① N-Ramanatha

UMU – 202

INSTITUTE OF
CORRESPONDENCE EDUCATION

B.A. Degree Course
Second Year

INDIAN MUSIC

Paper IV

Theory of Music – II

Package–1

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UNIVERSITY OF MADRAS
MADRAS–600 005

SYLLABUS – II

PAPER IV
THEORY OF MUSIC-II

I   Outline knowledge of the human voice box and the ear

II Musical sound and their characteristics -

    1   Pitch, Intensity and Timbre.

    2   Frequency and interval ;
       Relative frequencies of the 12 svarasthana-s and
       the values of the intervals between them.

    3   Free and forced vibration;
       Resonance, Sympathetic vibration;
       Beats and Combinations tones;

    4   Upper partials and Harmonics.

III Vibrations of stretched strings.
    Acoustic principles underlying   tambura, vina and
    violin.

    Vibrations of air columns.
    Acoustic principles underlying flute and nagasvaram.

V   Vibrations of stretched membranes.
    Acoustic principles underlying mrdangam and tavil.

VI a Outline knowledge of the different laksana-s of
       raga-s :

    1. Compositions from which the laksana-s have
       been deduced.

    2. Svarasthana-s   3. graha svara   4. amsa or jiva

    5. nyasa   6. melodic behaviour of specific svara-s

    7. sancara   8. aroha and avaroha

    b. Laksana-s of the raga-s prescribed for krti-s in
       Practical I and II.

VII. Laksana of krti form :

Contribution of - Pallavi Gopalayyar, Syama Sastri, Tyagaraja, Muttusvami Diksitar, Gopalakrsna Bharati, Anai-Ayya, Subbaraya Sastri, Vina Kuppayyar, Mysore Sadasiva Rao, Patnam Subrahamanya Ayyar, Pallavi Sesayyar, Ramanathapuram Srinivasa Ayyangar, **Muttayya** Bhagavatar Papanasam Sivan, Mysore Vasudevacarya, Kotisvara Ayyar, G.N.Balasubramanyam and Dandapani Desikar.

Brief biographical details of the above composers.

VIII. Knowledge of the following gamaka-s :

1. Kampitam   2. Sphurita   3. Nokku

4. Khandippu   5. Jaru   6. Odukkal

7. Orikal

IX. Study of the use of dvitiyaksara (edugai) and yati (monai) in musical compositions.

Technical terms – paada; anuprasa; antyaprasa padaccheda, yamaka, manipravala sahitya, svaraksara, gopuccha and srotovaha alamkaras;

X. Madras in musical compositions.

XI. Ability to reproduce in Notation the varnam-s and krti-s learnt in Practical I & II.

XII. Cycles of fifths and fourths.

IV – OVERVIEW

This package of learning materials contains the first five lessons as per the syllabus.

LESSON NO. 1

HUMAN VOICE BOX

Larynx or Voice-box :

The organ by which voice is produce is known as the larynx It is also popularly known as the voice box. This is situated beween the back of the mouth and the top of the wind pipe thus forming the upper part of the tube of communication between the external air and the lungs. Its position is marked by the projection in the throat popularly termed "Adam's Apple."

The sounds of the human voice are produced by a stream of air forced through a double reed which is coupled to a series of air cavities. The double reed -- known as the vocal chords, two horizonatlly stretched fibrous bands -- is situated just above the junction of the wind-pipe with the larynx It is in effect a pair of lips, not unlike the lips of the human mouth. The edges can be brought together and air from the lungs forced through between them. They will then be set in vibration, and will produce a peiodic interruption of the air blast, behaving much as do the lips of a bugler or cornet player. This gives the fundamental of the note that is sung or of the speaking voice, and the production of sound by using the vocal chords is known as phonation.

When an attempt is made to speak it is found that the edges are brought parallel and practically into contact with each other. The human voice is able to produce musical notes by the vibration of these vocal chords.

[See the enclosed figures]

Voice as a musical instrument :

On scrutiny it will be found that every musical instrument is made up of three chief parts, viz.,

(i) the vibratory system,

(2)　the means for increasing the volume of the sound which can be called for our purposes the resonator and

(3)　the manipulative meachanism for the production of the various notes of the musical scale.

Taking for instance the vina, it is seen that the main and subsidiary strings by their vibration generate the sound which is amplified by the bowl and the stem; for playing the various notes according to the musical scale the main strings are pressed against the frets by the left hand fingers. Frets are the short brass pieces which are fixed on the two ledges running along each side of the stem of the instrument.

In the vocal organ the lungs act as a kind of bellows increasing the pressure of the air below the chords and the issuing stream sets the vocal chords in vibration. The vibrations are then communicated in turn to the resonant air cavities formed by the larynx, the front and back parts of the mouth separated by the tongue and the nose. Variation in frequency is made possible by the muscles which control the width of the glottis, the portion between the vocal chords and the tension on the chords. Alterations in intensity of the notes are made by controlling the strength of the current of air through the glottis.

The vocal mechanism has been described by some physicists as resembling a stringed instrument and by others it is likened to a wind instrument. In fact its is a combination of both in that it resembles a stringed instruments in its vibrator and a wind instrument in its generator. More recently the view has been put forward that the function of the vocal chords is to induce vortex formation in the stream of air as it passes through the glottis and thus generate the sound. The shrill notes which we hear when the wind blows over the telegraph wires or through stalks of corn or blades of grass are cited as examples.

Voice in Men and Women :

The vibration of the vocal chords plays an important part in sound production. In men the natural length of these

chords is greater than in women and hence the voice shriller for women. The familiar phenomenon of the breaking of a boy's voice in his teens is due to the rapid increase in the length of the chords. The male speaking voice has an average fundamental frequency of about 145 cycles per second, with a range of 12 tones; while the female speaking voice has an average frequency of about 230 cycles per second, with a similar range.

Pitch of the note :

The pitch of the note produced depends on the thickness, tension, and vibrating length of the two 'chords', far torn which can be varied. The two chords lie in the same horizontal plane, and run from front to back. They open widely during the act of breathing, and are about 3/4 inch long in the case of men and about 1/2 inch long in the case of women. The 'cracking' of the adoloscent boy's voice is due to a comparatively rapid change in the length of the chords to about twice the previous value.

Tonal range :

The best human voice has a range of three and a half octaves, although in practice few people are able to sing in more than two octaves. In men two kinds of voice have been recognised viz. "The Chest Register" and "The Head Register". Between these two there is a break in the voice which is disguised by practice. At lower frequency the chest voice is employed. It is found then that the slit between the chords is very narrow and long and that the chords vibrate as a whole. For the higher notes the head voice is employed and in this case it is found that the vocal chords are wider apart with only their innermost margins vibrating.

Loudness of the voice :

The loudness of the voice depends mainly on the pressure at which air is forced between the vocal chords.

Quality of voice and Vowel sounds :

The characteristic by which we are able to distinguish notes of the same pitch and intensity coming from different instruments is known as "Quality or Timbre". The manipulation of the tongue and lips produces notable changes in the natural frequencies of th air cavities, and so modifies the quality of the note, the various vowel sounds being produced in this way.

The French mathematician Fourier has enunciated a theorem which states that any type of vibration however complicated, can be analysed into a series of simple vibrations of commensurate frequencies. So any musical note can be analysed into partial tones whose frequencies are once, twice, thrice or several times greater than the prime tone. It has been shown by the distinguished German scientist Helmholtz that the quality of a musical note depends on the number of these partial tones present and their relative intensities. It is the abundance of these overtones that produces the richness of the human voice and gives it the honoured place it occupies among instruments.

Another factor which places it in a class apart from all other instruments is the vowel qualities of its tone. It has been found that when different vowels are sung to any note, they are characterised by the prominence of one or more partials of definite pitch. This is ascribed to the alterations in the shape of the mouth cavity when the vowels are sung.

Voice training :

In training the voice, proper control over the muscles regulating the air stream and those concerned in the mechanism of the larynx should be obtained first. One has a certain amount of direct control over the muscles which regulate breathing and also over those which cause movements of the tongue, lips, soft palate etc.

the muscles of the larynx cannot be exercised independently. The control over them that makes singing possible depends entirely on the ear and the brain centres connected with it. It is because of this that deaf children can be taught to speak but not to sing. This is also obvious from the fact that one is able to sing raga-s perfectly by constant hearing alone without learning the theory of the combinations of notes.

If the breathing muscles are not properly controlled extreme unevenness of tone will result. One should take regular breathing exercises to increase the capacity of the lungs and to render the control of the air supply as complete as possible. The expiratory and laryngial muscles must act simultaneously. If the air stream precedes the action of the chords, the tone becomes breathy since some of the expired air escapes between the chords. If, on the other hand, the laryngial muscles act before the expiratory muscles, the air arriving at the glottis finds the exit closed and a further pressure of breath must be applied to separate the vocal chords before tone can result. This forcible opening of the glottis produces a "click" in the tone which can be easily heard and this fault is known as "Throatiness". This is not at all good as it unnecessarily fatigues the throat and gives the singer an agonised expression. If it is not corrected, it may result in a very common   disease among singers known as "singer's nodules" in the throat. It is suggested that humming exercises are often useful for curing this fault.

For general guidance to beginners it may be said that if the voice effort is felt in the throat it is certain that the production is wrong. If, however the singer is not conscious of effort in the throat but feels that the voice initiates at the waist, and that it is being produced in the chest it indicates that the production is correct.

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—Diagram of vocal chords and associated cavities. A, soft palate; B, pharynx; C, nasal cavity; D, hard palate; E, uvula; F, tongue; G, epiglottis; H, false vocal chords; I, vocal chords; J, wind-pipe

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Larynx

(a) Epiglottis
(b) False vocal cords
(c) True vocal cords
(d) Trachea
(e) Anterior wall of the Larynx

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VOCAL CHORDS

EAR

Structure of the Ear :

The ear as a physical instrument possesses remarkable characteristics; it stands foremost among all the receivers of sound. Its powers of analysis, its sensitiveness over wide ranges of intensity and frequency, the perception of direction by means of both the ears and many other phenomena have been accounted for recently. For convenience of description it is usual to divide the ear into three parts, the outer, middle and inner ear.

[See the enclosed figure]

Outer Ear

The outer ear consists of the external part known as the 'pinna'- the visible external part -, leading to the auditory canal and thence to the drum-skin.

* In animals pinna is often movable and is useful in discriminating the direction from which a sound comes. In the lower animals the pinna is provided with muscles and is capable of movement which helps them to collect sound energy from different directions. In man unless the ears are very pertruberant, it no longer performs either of these functions, and is at best ornamental, and not always that.

Leading from the pinna there is a passage called the 'auditory meatus', which is closed at its inner end by a very fine membrane, the tympanum or drum skin. It is the periodic variation of pressure in the meatus due to the reception of sound waves which causes the to and fro vibration of the drum skin, its vibrations being, of course, executed with the frequency of the pressure changes, and therefore the frequency of the waves.

Middle Ear

The middle ear is separated from the outer ear by the drum skin, to the inner side of which is attached the first of

a chain of three little bones or 'ossicles'. These, from their shape, are known as 'malleus', 'incus' and 'stapes' or hammer, anvil and stirrup. [See the enclosed figure]

This chain of bones, namely the ossicles, connects the drum skin with the small oval window or the inner ear. The stirrup is attached to the oval membrane and this separates the middle from the inner ear. The middle ear is a cavity completely enclosed except for a connection with the back of the throat through the 'eustachian tube'.

This tube, which is normally closed, but opens during swallowing serves a double purpose. It acts as a drainage tube and as a pressure equaliser. If the pressure of the air on the outer ear suddenly changes, and the pressure in the middle ear remains the same, the difference of pressure on the two sides of the drum skin prevents it from vibrating freely This happens, for instance, in a rapid aeroplane descent, and sometimes on a sudden entry into a tunnel in a train In these circumstances, we suffer from a temporary deafness, which is relieved at once by the act of swallowing. The function of the ossicles is to transmit the vibrations from the air in the outer ear to the fluid in the inner ear, with suitable modifications of the pressure and amplitude.

The behaviour of these three bones is an interesting physical study in itself. From the middle ear the eustachian tube proceeds to the pharynx. The tube opens when swallowing occurs and so helps to equalise pressures on both sides of the drum-skin. This quality is essential to hearing When one dives under water or goes up in aeroplane, the equality is lost and it may be restored by properly swallowing.

Inner ear

The inner ear consists mainly of the 'vestibule', the semi circular canals' and the 'cochlea'.

Vestibule : The vestibule is the middle part of the inner ear and contains the oval window which receives the foot of the stirrup. The oval window is a flexible membrane closing

the scala vestibuli at its base, while the round window is a similar membrance closing the scala tympani at its base. As liquids are nearly incompressible, this arrangement facilitates the movement of the oval window, as when it is driven in by the stapes the pressure is relieved by the round window bulging out, and as the stapes pulls out the oval window, the round window bulges inwards. In this way vibrations in the fluid are set up at the oval window, pass up the scala vestibuli, cross the membranes to the scala tympani, and return to the round window.

Semi-circular canals : The three semi-circular canals take no part in the mechanism of hearing but serve as an organ of balance. They are associated with our sense of the vertical.

Cochlea : The cochlea is the principal and the end part of the organ of hearing. As its name implies, it is shaped like a snail shell. It is filled with liquid and is surrounded by rigid bony walls. It is a spiral cavity in the bone consisting of two galleries, one over the other, divided by the basilar membrane, and communicating with each other at the far end where there is a break in the basilar membrane. The cavity is filled with a liquid. The basilar membrane has embedded in it a number of fibres varying in length from one end of the membrane to the other. The tensions on them are also found to vary accordingly. A system of nerves known as the auditory nerves connects the cochlea with the brain.

Process of hearing :

Sound entering the ear sets up minute changes in the air pressure in the ear canal and these cause the drum-skin to vibrate. This motion then passes through the chain of the tiny bones to the oval window. In this transmission these bones act as a transformer in communicating the vibratory energy from the air, a light medium, into the liquid, a dense medium. There appears to be an attempt here to reduce the displacement and increase the pressure amplitude in transferring these vibrations. That is, the chain of bones after receiving the motion of the comparatively large drum skin

moved by the air, changes it into the more forcible motion of the very small oval window which is communicated to the liquid within.

The processes within the inner ear are not fully understood and many theories have been advanced to explain its function. Of these theories, the resonance theory seems to be accepted by many. According to this theory the vibrations of the liquid in the inner ear affect the basilar membrance in different portions depending upon the frequency of the incoming sound, the high tones disturbing the thick end of the membrane near the oval window and low tones affecting the other end. Sympathetic vibration then takes place in the fibres in those regions and sensation is carried to the brain by the auditory nerves. Due to the very small dimensions in the ear the frictional forces are very large and consequently the damping is great. But for this heavy damping on the basilar membrane a rapid performance on a musical instrument would be audible as a jangle of notes. It means that vibration in the basilar membrane dies down so quickly that it is able to follow the changes without delay.

While a single ear can give some information concerning the direction of a source of sound, the use of both ears is necessary if accuracy is to be obtained. In the case of the eyes they have an additional advantages in that they help us to estimate both the direction and range. The directional properties of the ers are explained in terms of the intensity or phase theory according to the pitch of the tones heard. Thus for high-pitched sounds of short wavelengths these effects are explained by the difference in intensity of the sound reaching the two ears, the head functioning as a screen to the ear farther away from the sound source. At lower frequencies when the wavelength exceeds the circumference of the head the intensity theory alone was not found enough to explain the observations. Lord Rayleigh says that the judgement of direction is founded on the difference of phases at the two ears. This binaural faculty which enables us to get an idea of the direction in which a sound source lies was used during the first world war for locating hostile sounds with the aid of intensifying apparatus. The sound whose

direction was sought was usually that from an hostile aeroplane. Two long conical trumpets were used as artificial ears. These were mounted with their axes parallel at the ends of a struts weveral feet long which could be revolved so as to point towards the source. To know both the elevation and bearing of the aeroplane two pairs of trumpets were used. With the help of experienced listeners correct observation was made.

Musical perception and the ear :

1) The ear responds to pure tones over a range of frequency of ten or eleven octaves.

2) Pitch discrimination is acute over the middle of the range of audibility, but becomes less acute for notes of high pitch and much less acute for notes of low pitch.

3) When tones of nearly equal frequency are sounded simultaneously, we hear beats, but only when the musical interval between the two tones is not too large.

4) Two or more notes sounded simultaneously can be separately perceived, as can the constituent partial tones of a musical note.

We shall take up these points in detail.

Sensitivity to Pitch :

If we take a sound of variable frequency but constant intensity, and gradually increase the freqyency from 10 or 15 c.p.s., we shall at first hear nothing. Then, at a frequency which depends on the intensity we are using, the sound becomes audible as a note of low pitch. Increasing the frequency still further, the pitch continues to rise, until the sound becomes more and more shrill, and then suddenly it vanishes. The limits seem to lie at best at about 20 c.p.s. and 25000 c.p.s. or about 10 octaves.

The sensitiveness of the ear to notes of high pitch varies in a very marked way with age. Only the young can hear notes of frequency of 25000 and even in middle life the limit is much lower.

Sensitivity to tonal range :

The range of pitch to which the human ear is sensitive depends upon the individual. It also varies with time for the same person. The lowest frequency sensed as a note is given variously, but may be taken as about 16 vibrations per second. The highest pitch audible is also somewhat uncertain. Some are able to hear sounds upto a frequency of 40,000 per second. The extreme limits can thus be placed between 16 to 40,000 per second for musical purposes frequencies ranging from 40 to 50,000 per second alone are used.

Sensitivity to tonal intervals :

A matter of very great interest to the musician is the sensitiveness of the ear to small changes in pitch. This has been measured for pure tones in the laboratory by presenting successively to the ear two tones, one of which can have its frequency gradually increased. When the difference in pitch is just perceptible, the ratio of the frequency of the variable tone to the frequency of the fixed tone measures the just-perceptible interval of pitch. It is found that over the frequency range most common to music (500 to 4000 c.p.s.), and at the usual loudness level (about 40-60 phons), the ear can just discriminate an interval of less than one-thirtieth of a semitone.

Sensitivity to Intensity and Loudness :

There is a lower limit of intensity below which a sound is inaudible, and its loudness therefore zero. Before a tone can give rise to the sensation of hearing, the vibrations must attain a certain minimum amplitude. This minimum amplitude varies with the pitch of the tone. As the amplitude of the sound is increased, the sensation becomes progressively louder until a tickling is experienced. Still higher amplitudes cause actual pair. This sets the upper limit of audibility. At a

frequency of 1000 Cycles Per Second, the threshold intensity for a normal observer is taken as 0.00000000000000001 watts per sq. cm. The ear is most sensitive to sounds of frequency of about 3500 c.p.s.

Sensitivity to timbre :

Of all the special features of the human ear, its power of analysing a complex note stands supreme. As everyone is aware, the ear is particularly sensitive to that characteristic of sound which we call "Quality or Timbre". It has been shown by Helmholtz that 'Quality' depends on the number, intensity and distribution of the harmonic components into which a sound can be analysed. The ear possesses this remarkable faculty of doing the Fourier analysis of a complex note. It means that within limits depending on the training of our ears we are able to say what partial constituents are present in the note. The minuteness with which a trained ear is able to perceive dissonance between two notes further reveals its subtlety. The highly evolved scales in our systems of music show the way in which the ear is trained.

Aural harmonics :

The parts of the ear are constructed in an asymmetric way resulting in the ear generating harmonics of the sound it receives. If, for instance, a sound of frequenc f falls on the ear, then it adds the frequencies $2f$, $3f$, $4f$ etc.- in fact the full harmonic series. There is good reason to believe that the mechanism of the ear behaves in just this way, and that when a pure tone of sufficient intensity falls on it, the resulting sensation is that of a note of good quality with its harmonic partials.

That the ear can manufacture certain tones quite apart from those present outside the ear had been found out as early as the eighteenth century. It was Tartini, the famous violinist, who first noticed that when two notes a fifth apart in the middle of the scale were played on the organ, together with these notes a new low note was heard whose frequency was the difference of the two higher pitched notes.
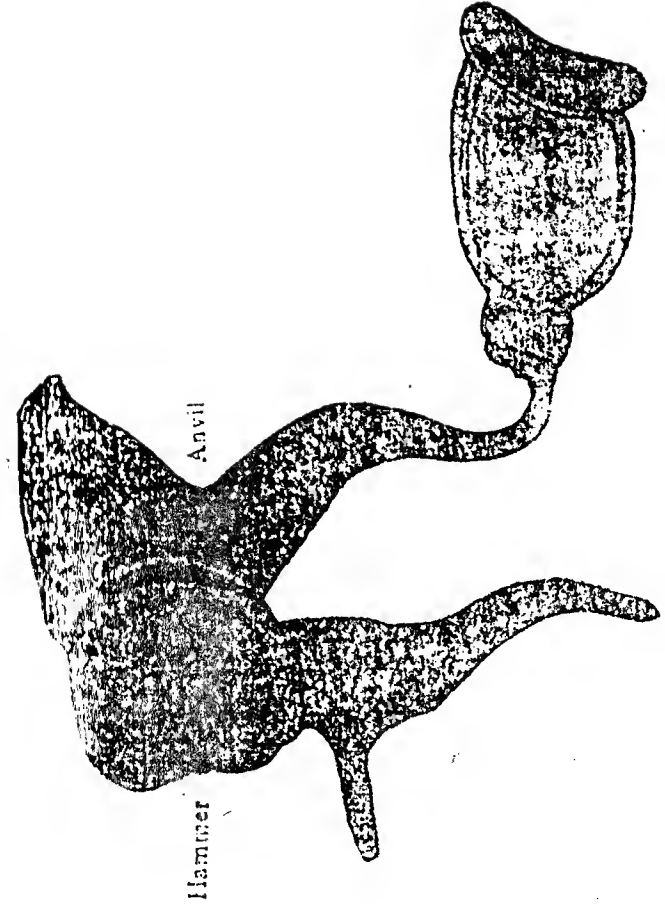
To give a familiar example the sound heard from a policeman's whistle is a differential tone. Helmholtz futher discovered another tone whose frequency is the sum of the original frequencies. These subjective combinational tones, as they were called, are attributed to the non-linear characteristic of the ear.

Books Referred :

1 "The Physics of Music" by Alexander Wood University of Paperbacks published by Methuen & Co. Ltd. London.

2 "The Physics of Music" by R K Viswanathan, published by The Annamalai University, Annamalai Nagar.

Three Semi-Circular Canals

Stirrup

Cochlea

Anvil

Hammer

Drum Skin

Eustachian Tube

எதிர் ஏகமான **EAR**

Anvil

Hammer

Stirrup

செவிப்பறையை எடுத்துக் காட்டி
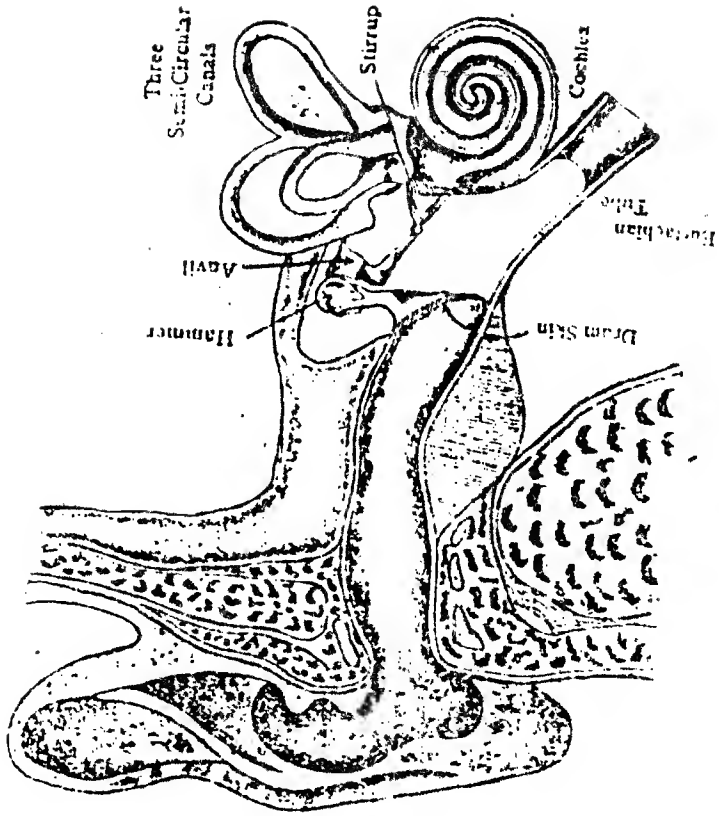
LESSON NO. 2

INTRODUCTION

Acoustics is that branch of physics which deals with the study of sounds, its cause and nature. While music is concerned with form and beauty that sound generates, acoustics is concerned with the problems of sound production, transmission, and perception of sounds in general.

Sound is produced by motion of some kind. In many cases the motion can be perceived by the eye. For example, when the string of a Tambura or Vina is plucked, it gives out a sound and at the same time the string swings from side to side. The moment the string is touched by the finger, the motion ceases and with it the sound. Thus sound is caused by the vibrating motion of some sounding body. In wind instruments sound is produced by the movement of the air inside a tube, and in the percussion instruments by the vibration of skin.

Musical sound and noise

It is an established fact that all sounds are not of the same nature. The first difference that we notice is between that of a pleasant sound and unpleasant sound or between a musical sound and noise. In the case of noise we hear rapid and irregular changes in the sound. When a balloon is burst or anybody screams or cries, the resultant sound is noise.

Production and Transmission of Sound

Sound is produced by vibration. In many cases the movement may be perceived by the eye. For example, we pluck the string of a Tambura or Vina, a sound is given out and at the same time the string swings to and fro. The moment the string is touched with the fingers the movement stops and with it the sound. Hence it is evident that the sound is produced by the vibrating movement of some

sounding body. To analyse the method of process, a sounding body for example, the string of the tambura, when sounded gives a series of backward and forward movements to the layer of air next to it. This layer of air is set in motion by the impulse of the force of the sound. This in turn strikes the third layer and so on, till the compression reaches the ....num or the ear drum. The layer of the compressed air just in front of the ear gives a blow to it and pushes it backwards. This movement of the ear drum is transmitted to the brain as sound.

We also see that the layers of air do not go forward, nor are they displaced, it is really fine state of compression and rarification of the air. So it only moves backwards and forwards but does not move away from its original position. This compression and rarification is known as sound wave. The following experiment will prove that it is the condition of the medium and not the particles of air itself that is carried to the ear.

Experiment :

Since air and water have the same qualities in the transmission of sound, the water is taken to prove the transmission of waves. The circular waves set up when a stone is dropped into still water is a phenomenon familiar to all. Stones dropped into still water will form water weaves which travel along outwards in larger circles. If small pieces of paper are floated on the water they will move up and down and not away from where they were dropped. The waves will be stronger at the place where the stone is dropped and the waves get weaker at the end. The move forwards till the extremities get weaker at the end. The same thing happens when air moves up and down. It is the disturbance that travels and not the air particle itself.

Transverse and Longitudinal wave propagation

There are two types of waves :

i. Transverse waves.

ii. Longitudinal waves.

Transverse wave is one in which sound is propagated in a direction perpendicular to the direction of vibration of the particle. Sound waves in stretched strings are tranverse waves.

In transverse wave propagation the direction of sound wave and direction of vibration of the particles are mutually perpendicular.

A tuning fork is used in the laboratory to emit notes of standard frequencies. It has two identical prongs forming a U connected to a stem called the shank. When the prongs are struck on a rubber pad they vibrate and emit notes of standard frequencies.

The intermediate particles arrange themselves in a wave-curve. As the prong vibrates, to an fro, the vibrations of the particles are repeated. You might have noted that the particles vibrate in a direction perpendicular to the line of propagation of the wave. In other words transverse waves are set up.

Longitudinal wave is one in which sound is propagated in a direction same as that of the vibration of the particle.

In longitudinal wave propagation the direction of sound wave is the same as or parallel to the direction of vibration of the particle.

When the prong vibrates to and fro, they push out the air particles in front and then pull them in forming condensations and rarefactions in the surroundings medium. As the prong continues to vibrate, alternate condensations and rarefactions are transmitted in the medium. The progression of these compressions and rarefactions is known as a longitudinal wave. Here also the particle does not move away with the disturbance and only energy is transmitted.

In the case of a transverse wave, the upper extreme position is called a crest and the lower extreme position is called a trough the crests of a transverse wave correspond to condensations of a longitudinal wave and the trough to rarefactions.

Medium

Sound requires a medium for transmission. Sound cannot be propagated through vacuum. This can be proved by the bell jar experiment. An electric bell is placed with in a bell jar and the jar is connected an exhaust pump. When the bell is connected to an electric battery it starts ringing. Now start exhausting the air from the bell jar by working the pump. The volume of the sound becomes lesser and lesser till one completely stops hearing it when all the air has been pumped out.

Now if the air is again let in, the sound begins to be heard again, softly first, and then gradually louder and louder. This shows that a vacuum cannot propagate sound. There should be some medium to carry the sound to the ear. Many kinds of sounds may also be propagated at the same time as is seen in a music hall or class room.

Air is not the only medium through which the sound is transmitted. Solid, liquid, and gas also transmit sound.

Placing the head against the table or bench, close one ear. Then sound a tuning fork and place the handle of the tuning fork on the table or bench. The ear is able to hear the sound very clearly. Again if one end of a wooden bar is held to the ear and other end tapped, the sound is perceived clearly by the ear, thus showing that solids transmit sound.

Vibrations are also carried through liquids. Suspend a tuning fork inside a cylinder with water. Set the fork to vibrate. Observe the note produced by the tuning fork. Then place a resonant box underneath the cylinder. Again repeat the same experiment. The sound will be reinforced by placing the cylinder of water with fork, on the resonant box. The vibrations transmitted through water is increased by the vibrations of the resonant box.

MUSICAL SOUND AND ITS CHARACTERISTICS

(a) Pitch, Intensity and Timbre

PITCH

Musical sounds arrange themselves in natural order according to pitch. It is the tonal variations that move up a melody when they are related to each other in a certain definite manner. Pitch is the height or depth of a note or that which distinguishes a note of lower sruti from a note of higher sruti. Pitch depends upon, frequency, which is the number of vibrations the sounding body makes per second. When the number of vibrations per second increases the pitch becomes higher and as the number of vibrations per second decreases and pitch becomes lower. While frequency is a physical quantity pitch is a purely subjective entity. It is one's judgement of how "high" or "low" a sound is.

If the frequencies of two notes bear the ratio 2:1, in former note will be found to be the octave note of the latter. This relationship is called Dvigunatva. The octave notes bear the dvigunatva relationship. In other words if the pitch of a note say like in Madhya sthayi antara ga is equal to 300 vibrations per second, the pitch of the tara sthayi antara ga is 600 vibrations per second and so on.

Pitch is expressed relatively when we say that one note is the Pancama or Madhyama of another note. It is expressed absolutely when its vibration number or frequency is mentioned. The pitch of a note can be expressed at the number of vibrations per second or it may be mentioned comparatively while comparing the pitch of a given note with another of the other.

It is necessary to define here two terms that have been used in the discussion above, namely, 'vibration' and 'frequency'.

Vibration :

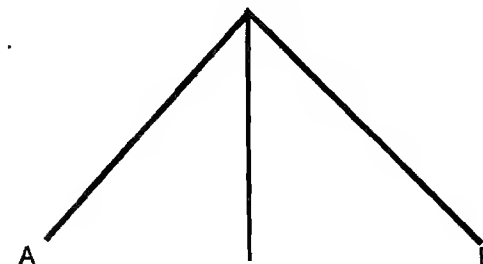Vibration is one complete to and fro motion.

Fig.1

In the fig.1 when the particle moves from A to B and returns to A we say the particle executes one complete vibration. The time taken to complete one vibration is called the time period of the vibrating body.

Frequency :

This is defined as the number of vibrations made per second by the vibrating body. When the frequency of a body is, say 256 hertz., this means that the body will execute 256 vibrations per second (the unit of frequency is 'hertz' (1 hertz = 1 cycle or vibration per second).

INTENSITY

Suppose the string of the Tambura is first plucked lightly and then with greater force, by drawing the string a little further from its position of rest, we are able to perceive a difference between the two notes though they are of the same pitch. We perceive that the intensity or loudness of the second is greater than that of the first. We easily recognise that the loudness of a musical note increases or diminishes with the amplitude or vibration of the sounding body. When the amplitude is larger the sound is louder and vice versa.

It is proved that intensity varies as the square of the amplitude. i.e., when the amplitude varies 3 times the intensity of sound varies by 9 times. In our houses if we want to have more loudness of the sound form the Radio we work on the volume control we manipulate to increase the amplitude to get louder sound.

The intensity is measured in terms of a unit called 'decibel'. A decibel is the smallest difference in the intensities of two sounds that the normal ear can distinguish.

We thus see that the intensity of the notes depends upon the amount of displacement of the string from the point of rest. It also depends upon the density condition in the temperature and the distance of the listener from the sounding body.

Intensity of sound is greater in a denser medium.

a. An electric bell sounds louder in a carbon di-oxide medium than in air medium as carbon di-oxide is denser than air.

b. Bell sounds louder in moist air medium than in dry air medium. This is the reason why a distant sound is better heard when the atmosphere is cold.

The directions of the currents of air and also the presence of other sounding bodies in the neighbourhood affect the intensity. In theatres with poor acoustics, inverted sound pots suspended over the stage serve as good amplifiers. For effective response, pots of various sizes should be used.

Here too, as in the case of pitch and frequency, there is a difference between intensity and loudness. Intensity refers to the energy of the sound waves, per unit area of wave front. Loudness, on the other hand, is the purely subjective response of the individual to that intensity. The greater the intensity, other things being equal, the greater the loudness, and vice versa.

The term 'amplitude' used above is being explained now.
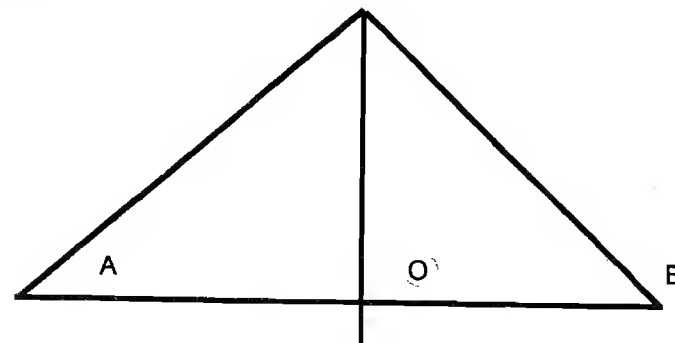
Amplitude :

Fig. 2

Amplitude of the vibration is the maximum swing OA or OB of the particle to either side of the equilibrium or rest position of the particle as can be seen in the fig.2 above.

Note :

1. The amplitude of the vibrating body gradually diminishes due to air resistance if its vibrations are not maintained by external arragements.

2. The amplitude of vibration of a body remain constant if it is situated inside a perfectly evacuated container.

TIMBRE OR QUALITY

Musical notes may also differ from each other by their quality. The quality or character of musical sound by which one is able to recognise the voice of different persons and the notes of different Musical instruments is known as timbre. Eventhough the sounds are of the same pitch and loudness, yet one can easily say which one has been produced by a Vina, which one by a Flute, Violin etc. A musical instrument

performs two functions. Some parts are designed for the production of musical vibrations and others receive these vibrations and amplify it. The quality of the instrument depends upon how these parts work together in co-operation. So it depends on the manner in which the sound is excited and also on the material and make of the instruments. In the case of the human voice quality depends on the size and strength of the larynx and the length of the vocal chords.

Helmholtz stated that the quality of a musical note depends on what overtones are present with the fundamental, on their relative frequencies and their relative intensities.

When a sound is produced there is present in it a fundamental tone or simply the fundamental and other higher tones called the Overtones or Upper partials (to be studied in the next lesson). The fundamental and the overtones originate from the same source and blend into single musicle note. If the frequencies of the overtones are integral multiples of the fundamental they are called harmonics. The number nature and the relative intensities of the overtones and harmonics determine the timbre or the quality of a note.

It is now known that there is also another factor of tone quality. This is the presence of what is termed a formant. This is a broad and continuous band of frequencies characteristic of a particular instrument. Whereas the overtones are discrete frequencies, are limited in number, and vary in pitch as the tone sounded by the instrument is changed, the formant has essentially all the frequencies in a fairly wide band and these frequencies do not change as the pitch of the musical note is changed. One class of instruments, such as the violin family (violin, viola, cello and the double bass), has a different formant than that of a different class such as the flutes. Within one class, such as the vina, different sizes will have somewhat different formants. But the fromants of vinas of different sizes will certainly have strong family resemblances.

In connection with sound and its characteristics it would be useful to familiarise ourselves with certain other terms.

Wave Motion

Wave Motion can be defined as the repeated motion of a series of particles, the motion being handed on from each particle to its neighbour. These compressions and rarifications which travel on to the ear drum are known as sound waves. A series of sound waves following each other in a medium along any line of propagation is known as Wave Train. The experiment illustrates the fact that it is a continuation of the medium and not the particles of the medium that is transmitted.

Wave Length

When sound is produced a series of compressions and rarifications are transmitted through the air and reaches the ear drum. One crest and trough in the water wave together make up a complete wave. [See enclosed figure] The crest is the place where the portion of the water has been thrust up from the original surface. The trough is the place where part of the water has been sunk blow the original. A cork floating near the place of disturbance will be found to remain in the same place riding over a crest and sinking under a trough as the waves move forwards. The distance between the two neighbouring crests or troughs is called the **wave length**.

In the air also one compression and rarification make a complete wave and the distance between two successive compressions or rarifications make up the wave length.

Wave Amplitude

The wave amplitude is the extreme distance or the extent of the vibration of the particle from the resting point.

Wave Velocity

The rate at which these vibrations advance is called Wave Velocity. The magnitude of the velocity depends upon the condition and density of the medium. If there are stronger forces or disturbances in the medium, the velocity is

feeble and there is no free course for the waves. When the medium is light the magnitude of velocity increases and when it is dense the velocity decreases. Thus the velocity of sound differs with different media.

Velocity of sound in a medium :

Distance travelled by sound wave in one second is called the velocity of sound wave.

Velocity of sound V = freqeuncy X wavelength

Reflection of Waves

Echoes are made by reflection. An echo will be heard only if the reflecting surface is far away from the source. If the reflecting surfaces is curved it may cause the sound waves to converge into a focus.

Refraction of Waves

Refraction, bending of the path of the sound which is travelling in a straight line, occurs when the sound waves pass from one medium to another because the wave velocity changes due to differring density and other conditions.

The change in the temperature also accounts for refraction. The change in the temperature increases or decreases the density of the medium. When temperature increases it lightens the medium and velocity increases and when the temperature decreases it makes the medium heavier and the velocity will be less. Waves travel faster in warmer air than in cooler air. The refraction caused by temperature variation is a very common occurrence.

Wind also produces refraction of sound waves as it is an established fact that sound waves travel better with the wind than against it. The velocity of the sound differs when we go up from the ground. In the higher attitudes there is only less scope for disturbances and also the pressure of the air changes when we go higher and higher. This causes the

sound to refract. The magnitude of the velocity hence depends upon the elasticity and density of the medium.

When sound passes through different media its frequency will remain constant, but wave length will change. hence velocity of sound is different in differet media.

2b. FREQUENCY AND INTERVAL

The physical state of any sounded note is given in terms of its frequency, which is number of vibrations the sounding body makes in one second.

The frequency is also given in terms of the length of the string that vibrates to produce that note and this is done always in relation to a fundamental note whose frequency is taken to be one (1). Frequency described thus is also referred to as '**Relative Frequency**' or 'frequency ratio'. Since the vibrating lengths of different notes are in simple ratio, the frequencies too are related thus. Knowing that the frequencies of vibrations are invrsely proportional the vibrating lengths, we forget about the lengths, and think in terms of frequencies.

For instance, the length of the string sounding the svara tarasthayi-sadja is half the length of the string vibrating to produce madhyasthayi-sadja. If the length of the string sounding madhyasthayi sadja is take as '1', then its frequency is could be roughly worked out as

1 ÷ L = 1 ÷ 1 = 1

The length of string producing tarasthayi sadja would be half of the previous one, in this case being 1/2 x 1 = 1/2. The frequency would be

1 ÷ 1/2 = 2

Thus the frequency of tarasthayi sadja is 2, assuming the frequency of madhyasthayi sadja is taken as 1.

By measuring the proportional lengths of the string producing the other notes we can compute their frequencies which are given below.

No.	Svarasthana	Frequency Ratio
1	sadja	1
2	suddha-rsabha	16/15
3	catuhsruti-rsabha	9/8
4	sadharana-gandhara	6/5
5	antara-gandhara	5/4
6	suddha-madhyama	4/3
7	prati-madhyama	64/45
8	pancama	3/2
9	suddha-dhaivata	8/5
10	catuhsruti-dhaivata	27/16
11	kaisiki-nisada	9/5
12	kakali-nisada	15/8

Musical Interval

The ratio between the frequencies of two notes is called musical interval. It is equal to or more than one and is never less than one. The interval is computed as the frequency of the higher note divided by the frequency of the lower note or the higher frequency divided by the lower frequency. The formula for this as follows.

I(interval) = F-H(frequency of higher note)F-L(freq. of lower note)

For instance the interval between sadja and catuhsruti-rsabha is

$$9/8 \div 1 = 9/8$$

Interval between pancama and suddha-madhyama is

$$3/2 \div 4/3 = 3/2 \times 3/4 = 9/8$$

Interval between pancama(3/2) and tarasthayi-sa(2) is -

$$2 \div 3/2 = 2 \times 2/3 = 4/3$$

Note :

In the last case the value of the interval is 4/3. '4/3' is incidentally the frequency-ratio of madhysthayi-ma also. Thus when we confront the fraction '4/3' then we should not immediately rush and identify it as the frequency-ratio of madhyama, it could also be the value of the interval between

a) pancama and tarasthayi-sa $(2 \div 3/2) = 4/3$

b) sadja and madhyama $(4/3 \div 1) = 4/3$

c) cat.rsabha and pancama $(3/2 \div 9/8) = 4/3$ and so on.

Some of the interval values are popularly referred to in terms of the important svaras between they exist. For example,

2	=	Sthayi or Octave [sadja - tarasthayisadja]
4/3	=	sa-ma [sadja - suddhamadhyama]
3/2	=	sa-pa [sadja - pancama]
5/3	=	sa-ga [sadja - antaragandhara]
9/8	=	catuhsruti [sadja-catuhsruti rsabha]

But, as pointed out above, each of these interval-values could represent the intervals between other pairs of svaras too.

Now, the above stated formula, namley "I = F-H ÷ F-L" can be used for calculating any one of the unknown factors among the three. That is, if the frequency of the lower note and the interval between the lower and higher notes are known, then the value of the frequency of the higher note can be found.

F-H = I X F-L

Similarly if the frequency of the higher note and the interval between the lower and higher notes are known, then the value of the frequency of the lower note can be found.

F-L = F-H ÷ I

With help of this we can calculate the frequency-values of the various svarasthana-s in mandrasthayi and tarasthayi. For example, the frequency of mandra-sa is 1/2 and can be calculated as shown below.

F-H, i.e., freq. of madhya-sa which is the higher note = 1 | (interval of octave or sthayi) = 2

F-L, freq. of mandra-sa which is the lower note = 1 ÷ 2 = 1/2

Similarly mandra-pa would be - 3/2 ÷ 2 = 3/2 X 1/2 = 3/4

Again the frequency of tarasthayi antara-gandhara would be 5/2 and can be calculated as shown below.

F-L, i.e., freq. of antara-gandhara which is the lower note = 5/4 | (interval of octave or sthayi) = 2

F-H, freq. of tara-sa which is the higher note = 5/4 X 2 = 5/2

LESSON - 2C

1. FREE & FORCED VIBRATIONS

A stretched string when it is struck goes on vibrating till it comes to rest. This vibration natural to itself is called free vibration and the period of its vibrations is called free period. But when this body forces another body whose period is different from its own to vibrate then the vibrations of the second body is known as forced vibrations.

Stretch a string between two stands and pluck it. Take a same kind of string and attach it on a sound board and pluck it. The second string will produce a richer and stronger sound. This is due to the fact that the sound board is made to vibrate by the vibrations of the string. Thus the vibrations of the sound board is called forced Vibration and that of the string is free vibration.

2. Sympathetic Vibration or Resonance

It is the phenomenon by which a body is made to vibrate by the vibrations of another body whose frequency is the same as that of the first. The vibration of the former is resonance or sympathetic vibration.

Experiment :

Stretch 2 strings A and B on a sonometer. Adjust their lengths by the bridges until the notes heard are in unison. Place a few paper riders on one of them and then pluck the other. The paper riders will begin to flutter vigorously and may be even thrown out. The second string will be going on humming eventhough the first is stopped. But the intensity of the second will be less than that of the first. The rates of vibration will be the same for both. The kind of vibration produced by the first string to influence the second is called the sympathetic vibration.

Sympathetic vibration is - if a string is set in vibration it will cause any other string to vibrate provided the other string is in close proximity and is tuned to the identical pitch or to any one of its upper partials. A very common, phenomenon noticed in the Tambura is that when the sarani is sounded the anusarani also vibrates, thus helping to produce a louder volume of sound. The sarani here makes the anusarani to vibrate.

Difference between Resonance and Forced vibration.

1. In resonance the frequency of the two sounding bodies is the same while in forced vibrations it is different.

2. In Resonance the vibrations of the second body is more vigorous than in Forced vibrations.

3. Very often the vibrations of the second body may be seen by the naked eye in Resonance where as this is impossible in Forced vibrations.

3. Beats

When two simple tones of nearly the same frequency are sounded at the same time, we do not hear them as two tones and instead, we hear a single note which rises and falls in intensity and these alternations in intensities are known as beats and they produce dissonance. That is, we hear one tone the frequency of which lies between the two and the intensity of which increases and decreases perodically. This periodic waxing and waning is known as beats.

The number of beats heard in one second can be said to be equal to the difference between the frequencies of the notes producing the beats.

The beats will be slow when the difference in frequency is small. But as the difference increases the beats will be produced more rapidly. When they are slow their effect may be moderately pleasing. But when they are rapid it becomes more and more unpleasant. But when they become still more rapid the unpleasantness decreases since it becomes a full next note higher or lower.

Experiment :

Adjust the length of two vibrating strings by a bridge until the notes emitted by them are in unison. Now change th pitch of one of the strings slightly and then sound them together. Beats will be slowly heared. Change the tension of the string still more and see whether the beats are made slowly or more rapidly. If the beats are made slowly that shows the unison is being approached. If it is more rapid, then we are going further from the unison. Then the string should be adjusted in the direction till the beats finally disappear. Thus by listening to the beats we are able to tune the musical instruments accurately.

Experiment :

To show that the number of beats heard per second is the difference between the frequencies -

Consider two tuning forks A and B of very equal frequencies say 240 and 244, which are sounded together. After 1/8th. of second A completes 30 vibrations and B completes 30.5 vibrations. Minimum sound is produced. After 1/4th. of a second A completes 60 vibrations and B complete 61 vibrations. Maximum sound is produced. Thus in 1/4 seconds 1 maximum and 1 minimum are produced. In the full one second 4 maxima and 4 minima are heard. The sound waxes and wanes 4 times per second i.e., 4 beats are heard. Here the difference in frequencies is (244-240) = 4 therefore the number of beats heard per second is the difference between the two frequencies. The same thing happens when the frequencies are, say, 240 and 236.

4. Combination tones

Consider two strong of frequencies X and Y. When they are sounded together it can be shown that by mathematical analysis a series to tones of other frequencies are produced along with the original one. These tones are called Combinations tones. One should not confuse these combination tones with the harmonics accompanying a fundamental note. Combination tones are classified into two categories.

i. Difference tones   ii. Summation tones.

The famous violinist Tartani was the first to observe this tone. So this tone is called Tartanian tone. It is a very common occurrence and we can find this applied in policeman's whistle. When it is blown the air passes through the mouths of these two pipes of unequal length and the different tone of these 2 pipes when blown together is heard very loudly.

For instance, if there are two tones of frequencies 550 and 320 vibrations per second which are sounded together , then we will hear in one tone of the value 870 (550 + 320) and one of the value 230 (550 - 320). The resulting combination tones would further interact to give more combination tones like 550 + 230, 320 + 870, 870-230, and so on. The harmonics of the basic tones will also play part in the combinations tones.

Difference Tones :

The tone of frequency (X-Y) or (Y-2X) is called the first difference tone. It is the strongest of the combination tones (X-Y) and Y can produce a difference tone of frequency (X-2Y) This is the second difference tone. Like this infinite number of difference tones of frequencies

(X-Y) (X-2Y) (X-3Y) (X-4Y) ....

or

(Y-X) (Y-2X) ....is theoretically possible.

Summation tones :

In a similar manner one can expect summation tones of frequencies (X + Y) (X + 2Y)..........(Y + 2X) ....etc. In fact an infinite number of summation tones is also possible theoretically. But only the first difference tone is audible and even that is weaker than the two primary tones. The second third etc., difference tone and summation tones are extremely weak in intensity and therefore not at all audible.

LESSON NO. 2D

UPPER PARTIALS AND HARMONICS

A musical note may be rendered in a plain or unadorned manner and in a graced or decorated manner according to the raga in which it occurs. On examining the effect produced on the ear by a vibrating string which produces a musical note, in addition to the fundamental note we are aware of a series of higher tones which are called harmonic or upper partials of the fundamental note which is the lowest and loudest of all the tones.

If we strike a string of any instrument provided it is at proper tension, we see that it vibrates not only in its entire length but also in parts. What happens is that the string divides itself into 2 or more separate vibrating parts of equal

lengths with fixed points called Nodes separating them. All these vibrations are simultaneous and the sounds proceeding there from are blended into one. It vibrates first in its entire length and then in 2, 3, 4, 5 sections etc. The fundamental Sa which is produced by the entire length is the loudest and is called the prime tone, while others are called the upper partials or overtones. [See the enclosed figures]

The fundamental tone and the series of upper partial tones which conform to a ratio of 1:2:3:4:5 etc. constitute the **Harmonics.**

For instance, the first upper partial tone is the higher octave of the fundamental. sa and makes twice as many vibrations as the prime. The second upper partial tone is the Tarasthayi Pa and makes thrice as many vibrations as the prime. The third upper partial tone is the second higher octave and makes 4 times as many vibrations as the prime tone and it is Atitarasthayi Sadja. The fourth makes 5 times as many vibrations as the prime and it is Atitarasthayi Pa. Thus the relative frequency values of the vibrations which make the harmonic series are related as 1:2:3:4:5. Thus while all overtones need not necessarily be part of harmonics series, all harmonics are overtones.

The term 'Svayambhu-svara' mentioned in the ancient Samskrta treatises on music corresponds to the harmonics.

When the strings of a well tuned tambura are plucked then in the string tuned to mandrasthayi-sadja the antara-gandhara overtone is heard. The antara-gandhara heard is that belonging to tarasthayi. This would be clear from the following calculations.

Frequency of mandra-sa = (freq. of madhya-sa) 1 ÷ = 1/2

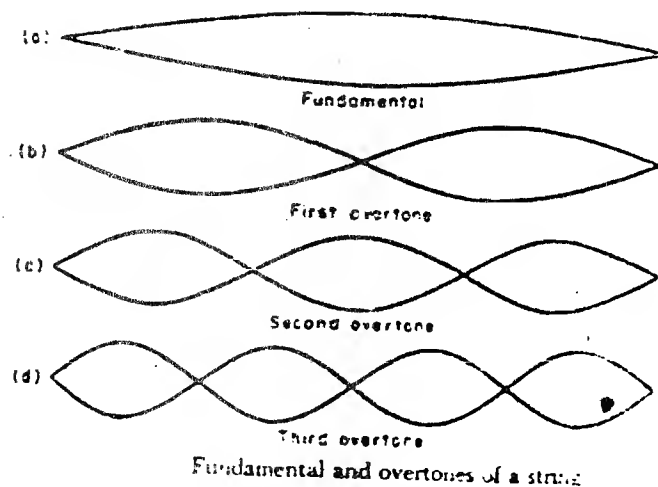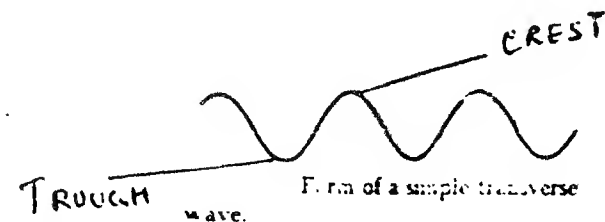The harmonics produced on this string, calculated through the ratio 1:2:3:4:5 etc. would be

First harmonic - 1/2 X 1 = 1/2 (mandra-sa)

Second harmonic - 1/2 X 2/1 = 1 (madhya-sa)

Third harmonic - 1 X 3/2 = 3/2 (madhya-pa)

Fourth harmonic - 3/2 X 4/3 = 2 (tara-sa)

Fifth harmonic - 2 X 5/4 = 5/2 (tarasthayi-antaragandhara)

The timbre or the quality of a musical tone will depend on the number and strength of the overtones.

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  Munshiram Manoharlal Publishers Pvt. Ltd., 1981.

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Form of a simple transverse wave.

Fundamental and overtones of a string

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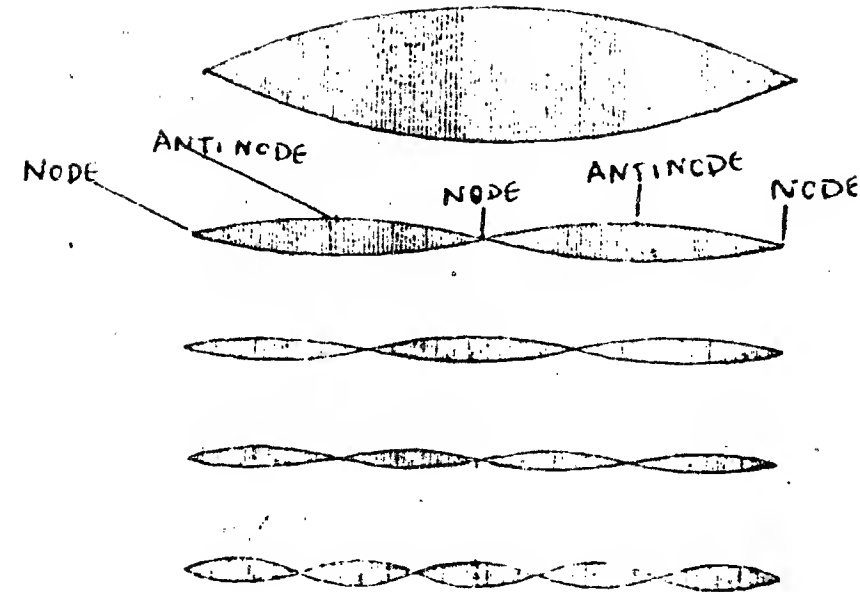
கம்பி ஒல்வது தால் துடிக்கும்போது உண்டாகும்
பல கண்டங்களை விளக்கும் படம்

LESSON NO. 3

VIBRATIONS OF STRETCHED STRINGS

When a string is not producing sound it is said to be in a position of rest. If now it is pulled slightly to one side and released it moves backward and forward in an uniform manner, till the sound dies out. The backward and forward movement is known of vibration. That is if A is the position of rest and if the string moves to B on one side and back again to A, then the string is said to have made a complete vibration. Half of this movement is an oscillation.

The distance the string has travelled on both sides of the position of rest in known as the amplitude of the vibrations. Amplitude is the extent of vibrations. When a string is set in motionthe middle part which is seen to move backwards and forwards is known as the antinode. There are two points of rest where the strings are fixed and these two points are known as the nodes. There is no motion on these two points which are the points of rest or the nodes.

[See the enclosed figure]

Laws of Vibrations of Strings

Mersenne (1588-1648) of Paris with the help of the monochord or Sonometer [see the enclosed figure] in order to study the variations in frequencies of the stretched strings. It consists of a hollow wooden box on which a wire is fastened to a peg and passing over a pulley, the wire is kept tight by a weight. There are 2 movable bridges on the sound box on either side to adjust the variations in vibrating length. The purpose of the sound box is to give tonal effect to the sound emitted by the strings. He found out by experiments that the pitch of the strings depends upon 3 important conditions.

1. The frequency of the notes emitted by a string kept under constant tension varies inversely as the length i.e., the greater the length, the lower the pitch.

Experiment :

Keep the two bridges 90 cms apart and pluck the wire and see the notes produced. Arrange the bridges in such a way as the string will vibrate in its half of its length producing a note an octave higher than the first. By successively stopping the string at a third and a quarter of its length the notes tarasthayi-Pa and atitarasthayi-Sa are heard by the respective lengths.

The frequency of the notes emitted by a string kept under a constant tension varies inversely as its length. The greater the length of the string the lower the pitch or the shorter the length the higher the pitch.

Students of music can easily see this in the musical instruments like Vina and Violin. When the finger is kept on the first fret and the subsequent frets, the length of the string gets gradually reduced and the pitch gradually increases.

Likewise longer Flutes and Nagasvaram produce lower notes while shorter ones give out higher tones. In percussion instruments the smaller drum faces give higher tone and bigger ones give lower tones.

2. The frequency of a note emitted by a string whose length is kept constant varies directly with the tension I.e., the greater the tension the higher the pitch.

Experiment :

Fix a strong string on the Sonometer and keep the bridges in a fixed position. After tuning it in unison with a tuning fork, now double the weight in the pan at the end of the string, thus doubling the force of tension. The pitch of the note now rises but not to the level of the next octave note. Add more weight till the next sthayi svara is obtained. The weight is now found to be 4 times that of the original. With 9 times the original weight tarasthayi-Pa is heard and 16 times the original will give a note 2 octaves above the fundamental. So while the frequencies are in the ratio

1:2:3:4, the tensions are in the ratio 1:4:9:16, the greater the tension the higher the pitch.

In the stringed musical instruments the tension of the strings is increased by means of the pegs. When the peg is turned in one direction the string gets tightened and loosened when turned in the other direction and consequently the pitch increases and vice versa.

In wind instruments the force with which the wind is blown into the tube helps to get the pitch higher. In percussion instruments the pitch is increased or decreased by tightening or loosening the leather strap. Thus tightening or loosening the drum faces changes the pitch.

3. The frequency of a string kept at constant tension and length, varies inversely with the mass of the string i.e. the greater the thickness of the string, the lesser the pitch or the pitch or the frequency.

Take four strings of the same material and quality but with diameter in the ratio 1:2:3:4. Set them up side by side on a sonometer and stretch them by equal weights. If we pluck them, the thickest will have the frequencies in the ratio of 1:1/2:1/3:1/4 from the thinnest to the thickest. So the thicker the string the lower the pitch.

In wind instruments flutes with thicker walls and those with longer circumference give lower notes and flutes with thinner walls and smaller circumference give higher pitches. In percussion instruments, those with thicker skins will give lower note and those with thinner skins will give higher notes. This is the volume of sound produced. The same note may be produced with varying loudness.

These laws can be mathematically expressed as follows.

If

n = the frequency of the fundamental note

L = the length of vibrating segment of string

T = the tension of the string $(T = mg)$

{m = mass of the land &

g = acceleration due to gravity}

M = Linear density or mass per unit length of the string

i. Tension 'T' and Linear density (M) being constant, the fundamental frequency of the note 'n' is inversely proportional to the length of the string

n is $\propto 1/l$ (or)

nL = K 1\L where 'K' is a constant (or)

nL = K = constant

ii. 'L' and m being kept constant 'n' is directly proportional to T
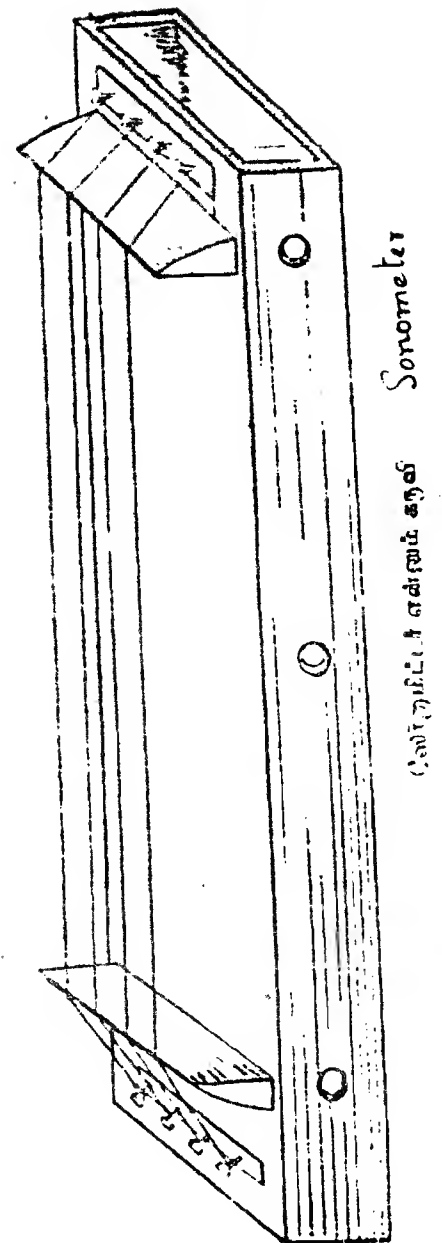
n is $\propto \sqrt{T}$ (or)

$n^2 \propto T$ (or)

n^2 / T = constant

iii. 'L' and 'T' being constant,

'n' is inversely proportional to M

i.e., n $\propto 1/M$ or $n^2 M$ = constant

Sonometer

Acoustics principles underlying
Tambura, Vina and Violin

Tambura, Vina and Violin, the chief concert musical instruments, come under the class of instruments called Stringed or Stretched stringed instrments, the common feature in them being that the sound production takes place due to the vibration of the strings. While tambura is a 'sruti-vadya' with each of the four strings constantly generating only the svara-s to which each one is tuned, in vina and violin a variety of notes are produced in each string, the combinations of such notes giving rise to a melody. Further the vina and violin differ with respect to construction and modes of sound production, the former being a plucked one and the latter a bowed one. It is hence necessary to know the principles on which sound production takes place in each of these and acoustical reasons for the quality of sound that is characteristic of each instrument.

Tambura

1. Strings and tuning :

Tambura, as you are aware, has four strings tuned to —

mandra-pa, madhya-sa, madhya-sa, mandra-sa.

The lengths of different strings are same. They should have almost identical tension otherwise the uniform volume will not be obtained. Since length and tension are same different pitches are achieved by having different thickness and material in the strings. In the case of tambura-s tuned for female voices, i.e., tuned to 5-kattai or 'G', the madhya-sa strings are of steel and of the gauge '29' or '30'. For mandra-pa the strings are thicker having the gauge number '27' or so. For mandra-sa the strings is a steel one with copper-foil wound over it. Thus in obtaining the different pitches the third-law of vibrtions of strings is seen to be in action.

For changing the pitch of a string the pegs are turned. By turning the peg and refixing it the tension gets altered.

Similarly when the 'bead' or 'manikkaai' is pushed towards the end of the ledge it increases the gap between the string and the top plank by pushing the string up, thus increasing the tension. Thus the pitch goes up. When the manikkaai is pushed towards the bridge the gap is reduced, consequently the tension is lowered and the pitch goes down.

2. String-Bridge Contact :

The bridge on the board of a tambura resonator is wide and curved. The strings pass over the arched bridge tangentially. In instruments like the violin, sarangi and sarod the bridge is not wide and has no curvature but is sharp-edged.

In the case of a stringed instrument with sharp bridge, Young-Helmholtz law states that harmonics requiring a node at the point of plucking are absent. That is, the point at which the string is being is plucked or bowed will not form a node and harmonics requiring that point to be a node will not be produced, in other words, that point will have continuous displacement.

In the case of tambura (and vina) which have wide bridge this law is not found to be obeyed. That is, in these instruments harmonics having node at the point of plucking are also found to be produced. This peculiar behaviour, as explained by C V Raman, is due to the nature of the contact of the string and the bridge of the instrument.

The nature of the string-bridge contact in instruments like the violin, that is, those with sharp-edged bridge, may be taken to be almost a point contact, i.e., the string rests on the bridge on a fairly well-defined point and does not change this point of contact appreciable during playing. In instruments like the tambura (vina, sitar etc.), due to the slope of the bridge, the string-bridge contact is grazing one and is never a definite point. As a result plucking a tambura gives rise to a very rich series of harmonics not usually present in other types of stringed instruments.

3. Role of Jivaa :

A cotton thread or 'jivaa' is place under each string of the tambura.

In this position of the jiva, the string just touches (or is just above) the bridge surface, so that during vibration, the string gets lifted in its upward motion and touches the bridge at the point of contact during its downward motion. The string thus strikes the bridge periodically in the course of its vibration. Further, during the upward motion of the string, the end nodal point suddenly jumps from the point of contact to jiva position and during the downward motion the nodal point jumps back to the point of contact and slightly drifts towards the left.

Collisions of the string with the bridge generate harmonics in the string and the string starts "quiverring". Initially when the amplitude is large, contact (with the bridge) and no-contact timings during collisions are equal. But soon after, as the amplitude of the string decreases, the collisions split up into four, then, three, then two and finally one interval of shorter duration.

In other words, the vibration has string touching the bridge at a point before the jiva (towards the dandl), and at the jiva and finally at a point on the bridge beyond the jiva (towards the ledge or manikkaai).

This means that there is a periodic damping of the vibration of the string at the point of contact with the jiva, so that there is a periodic change in the length of the string and shift of the node from the point of damping to the point of permanent contact (most probably beyond the thread). This would account for the periodic change in the fundamental frequency and the production of unusual number of harmonics, inharmonics and subharmonics - not only in a very densely ordered set, but in the form of impulses. A careful listening to tambura will show that the tones of the instrument (specially some of the harmonics) are not heard continuously but in spurts.

It is, therefore, necessary to take into account, at least in the case of the tambura, this periodic damping of the string besides the effect of the slope of the bridge. The curvature of the bridge may account for the behaviour of the strings of vina etc. but must be deemed insufficient in the case of the tambura. For it is obvious that, even without the jiva thread, the bridge is still a sloping one and hence the string-bridge contact is a grazing one. Consequently it is necessary to note that the thread introduces a further factor than merely increasing the curvature; it makes possible for the string to leave the bridge and hence be damped periodically. The bridge of the tambura without the thread may be similar to that of the vina, but with the thread it may be essentially different. [See the enclosed figure]

From the above discussion we infer one important point that the shifting in the point of contact between the string and the bridge causes slight variations (0.5 to 1 percent) in the frequency of the fundamental note and those of the harmonics.

4. Plane of vibration of strings :

There is a difference in the mode of vibration of the tambura and that of a normal (sonometer) string. This lies in the extent of vibration in various planes. Strings vibrate all planes, vertical, horizontal and angular. In the case of the tambura the horizontal and other angular components are as prominent as the vertical one, which is not the case in the normal string where the vertical movements are more prominent.

5. Role of Kudam :

The kudam is referred to as 'resonator'. Strangely it does not perform the task of resonance. The resonator is a hollow wooden bowl. The vibrations of the strings are transmitted to the kudam through the bridge (that is why the brdige is so named). The vibrations generate forced vibrations in the kudam and the volume of air it encloses. The vibrations are transmitted to the "dandi" which too is hollow and encloses a coloumn of air. The vibrations of strings are

thus transferred to a larger area and are re-transmitted to the air outside and consequently to the listeners. Thus the sound of the strings are amplified.

On the top plank, on either side of the bridge, small holes are drilled in circular formation. These help in establishing communication between the air outside and inside for purposes of better transmission.

The nature of wood used and the shape of the kudam shape of the kudam bestow a quality to the sound produced. Without the attachement of the kudam the sounds of the strings would be 'mettallic' in character.

Vina

There are many aspects which are common to both tambura and vina.

1. Strings and tuning :

In the case of vina there are seven strings. Four main strings are for playing melody and the three side strings are for sruti and tala.

a) The strings are of different gauges as in the case of tambura and thus they are tuned to different pitches.

b) Fine adjustments in pitch are made sometimes by shifting a spiral string moving over the langar. Shifting this adjuster away from the bridge presses the metal fastenings of the langar against one another and increases the tension. This results in the increase of pitch (Second law). Shifting the aduster towards the bridge reduces the tension and thus decreases the pitch.

c) On the main strings different notes are produced on each string. For instance, on the first, that is the strings tuned to madhya-sa gradually higher pitched svara-s are produced by placing the finger on different frets and moving towards the bridge. When a finger is placed on the string and

pressed against a fret, the length of the string is reduced. A shorter length of the vibrating string will result in higher frequency as stated in the first law of vibration of strings.

d) Quite often higher pitched svara-s are produced by pulling the string and deflecting it. In this case the tension is being increased and this results in the increase of fequency as stated in the second law.

2. String-Bridge Contact :

The bridge on the board of a vina is resonator is wide and curved, similar to that of the tambura. Same principles that operate in tambura and which have been discussed in the context of tambura above, are also applicable to vina.

That is, in these instruments harmonics having node at the point of plucking are also found to be produced. Due to the slope of the bridge, the string-bridge contact is grazing one and is never a definite point. As a result plucking a vina gives rise to a very rich series of harmonics not usually present in other types of stringed instruments.

However since the vina does not have a jiva it is different in that respect from a tambura.

3. Role of Kudam :

Kudam in vina has the same role to play as the kudam in tambura as discussed above.

In the case of vina there is another small kudam at the other end attached to the dandi and referred to as 'suraikkai'. This serves as a rest for placing the vina on the thigh. Question is often asked whether this small kudam would also fuction as a resonator.

The small kudam is open at the lower side and is not a container of a volume of air as is the main kudam. However any hollow part attached to an instrument would certainly contribute its might as a resonator, however small that contribution might be.

தம்புராவின் தசை   BRIDGE OF TAMBURA
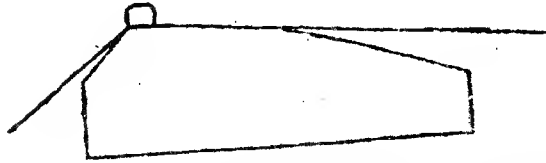
வீணையின் தசை   BRIDGE OF VINA

Violin

Violin differs from the two instruments discussed above in that the sound is produced by bowing while in the other two it is done through plucking.

1. Strings and tuning :

Violin has four strings tuned to —

madhya-pa, madhya-sa, mandra-pa and mandra-sa.

With length and tension remaining the same the different pitches on the different strings are obtained by having strings of varying thickness (third law). The first string is usually a plain stainless-steel string while the others of stainless-steel strings of different gauges with chromium plated foils wound around them.

The higher pitched svara-s are played on a string by 'stopping' the string with fingers of the left hand, i.e., by placing the finger on the string at various positions on the finger board. This reduces the vibrating length of the string resulting in svara-s of higher frequencies (first law).

2. Process of Bowing :

The bow consists of strands of horse or nylon hair stretched between the two ends of the bow-stick. The resin or rosin applied to the hair leaves on the hair gum- powder. These help to create a friction between the hair and the string. Hence when we move the bow over the string, it draws the string aside, the tension of the string supplying a gradually increasing force. tending to make the string slip past the hairs of the bow. When the friction can no longer hold the string against the bow, slipping takes place, and the string slips back to its undisplaced position and beyond. Presently it comes to rest, is again caught by the bow, and again displaced until it slips once more.

Bowing, in a way, is nothing but a series of plucks coming so quickly in succession that the individual plucks

cannot be distinguished and the resultant sound is not a set of discrete pitches but one continuous sound.

The force between the bow and the string is little greater as the bow draws the string aside than it is as the string slips past the hair. This is due to the fact that it always takes more force to start a body moving aginst friction than to maintain it in motion once slipping has started. It is interesting to notice that all the music produced by bowed-string instruments depends on the very small differnce between the maximum force of friction when string and bow move together and the force when the string is slipping past the bow.

Bowing and quality of violin tone :

It is found that quality of tone is affected very little by the bowing pressure, but more by the speed of the bow. The factor which is most important, however, is the point of attck on the string. If the bow were extremely narrow the tone of the string would contain very prominent high partials and the quality of tone would be independent of the point at which the bow was applied. If the point of bowing is nearer the bridge then quality of tone is bright. But nearer the bow is to the bridge greater should be the bowing pressure. The region within which the bow usually touches string is about 1/7th to about 1/15th of the length of the vibrating string from the bridge. The more common practice is to choose a position at about 1/9th or 1/10th of the length of the viebrating string from the bridge.

3. The 'Wolf'-Note :

In the violin the bridge, the belly, the back and the contained air all take part in the vibration. Each of these has its natural frequency at which resonance may take play. That is, if the frequency of the svara being produced is the same as the natural frequency of any one of the the parts then the part will resonate.

Most bowed instruments have one svara which is difficult to produce satisfactorily and which tends to give a 'howling' quality. It is called the 'wolf' note. As the string is coupled to the belly of the instrument through the bridge and its natural frequency coincides with one of the natural frequencies of the belly, this latter will rapidly increase its amplitude, taking energy from the string until the bow is no longer able to maintain the ordianry form of vibration.

There are two ways to get over this problem. One is to apply greater and appropriate pressure on the string with the bow. The other is to 'load' the belly by attaching a 'mute' to the bridge. Mute is metallic clip-like object, with three parallel legs, that is clamped to the top sharp edge of the bridge with each leg being inserted between the gaps between two strings. This load increases the inertia and diminishes the natural frequency of the belly and the wolf-note is found to have dropped in pitch.

4. Transmission of vibration :

The vibrations of the strings are transmitted to the body or the resonator mainly through the bridge and the sound post.

Bridge :

The bridge transmits vibrations from the strings to the belly. It seems to be designed to eliminate the longitudinal vibrations of the string (those in the line of the string). The right folit of the bridge, being almost over the sound-post, moves very little, so that the bridge rocks about this foot in its own plane, the left foot setting the belly in vibration, and these vibrations being commucicated from point to point in the wood of the instrument and from the wood to the contained air.

Sound post and Bass bar :

Sound post as pointed out above helps in transmitting the vibrations from the belly to the back of the violin body.

The Bass-bar that is located under the left foot of the bridge is a bar glued to the underside of the belly, and known as the bass bar. It runs longitudinally, distributing the pressure and transmitting the vibrations more rapidly.

Books referred :

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3 "The Music of India : A Scientific Study"
   by B Chaitanya Deva,
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4 "Principles of Physics" by Earnest Greene,
   Prentice-Hall of India Private Limited,
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5 "Physics of Tanpura : Some Investigations" -
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LESSON NO. 4

VIBRATIONS OF AIR COLOUMNS

The familiar phenomenon of the sound obtained by blowing across the open end of a key shows that vibrations can be set up in an air column. An air column of definite length has a definite natural period of vibrations. When a vibrating tuning fork is held over a tall glass tube, placed in a cylinder of water into which water is poured gradually, so as to vary the length of the air column, a length can be obtained which will resound loudly to the note of the tuning fork. Hence it is easily proved that the number of vibrations of the air column is the same as that of the tuning fork.

Experiment :

Support a glass tube open at both ends in a vertical position, with its lower end dipping into water contained in a wider cylinder. Holdover the upper end of the tube a vibrating tuning fork. Adjust the position of the tube so that the greatest reinforcement of the sound is obtained. Adjust the distance of the air column till we get actually the resonance or sympathetic note. Repeat the adjustments and take the average of the results from the observations. It will be found from the repeated experiments, that the longer the air column the lower the pitch. The resonance of the air column is produced when the pitch of the air column as well as the pitch of the tuning fork becomes identical. [See the enclosed figure]

Vibrations of air columns can be studied with respect to pipes which are open at both ends and with respect to pipes closed at one end. A flute is an instance of an open pipe while a nagasvaram is a pipe closed at one end.

Vibration of air coloumn in a tube open at both ends :

If we think of an air coloumn in a tube open at both ends , and try to imagine the ways in which it can vibrate, we shall

readily appreciate that the ends will always be antinodes, since here the air is free to move. Between the antinodes there must be at least one node, and here the air is preserved at rest because, at the ends, the moving air is either moving towards the centre from both ends or away from the centre at both ends. Thus the simplest kind of vibration has a node at the centre and antinodes at the two ends.

an	n	an
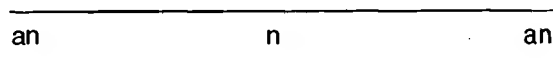
This can be mathematically expressed as follows.

Wavelength as defined earlier in Lesson no. 2 is the length between any two similar points in the waves, or say between the commencing point of a wave to the commencing point of the next wave. In other words, since every wave has two nodes and two antinodes, wavelength would be distance between first node to the first node of the next wave, i.e., the third node or between the first antinode and the third antinode. Since the length of the tube extends from one antinode to second antinode the wavelength will twice the length of the tube.

Thus the wavelength will be 2L, where L is the length of the tube. If N is frequency, V the velocity of sound and 2L the Wavelength then

$$N = V/2L$$

Overtones in Air coloumn in Open tube :

As with the string, in air coloumns too overtones are produced. [See also the enclosed figure]

Fundamental tone :

By definition, the fundamental will have the lowest frequency and hence the greatest wavelength. The length

would be 2L, i.e., twice the length of the tube. The frequency N will be

an	n	an
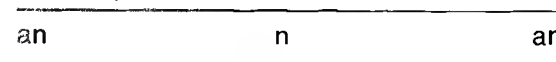
$$N = V/2L$$

First overtone :

The first overtone must have a higher frequency and thus a shorter wavelength than the fundamental, but it must have also an antinode at each end. So a node, an antinode and a node have the inserted.

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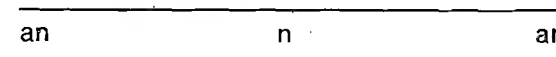
The wavelength will then be equal to half the length of the wavelength of fundamental or between the first and the third antinode, i.e., equal to the length of the tube, i.e., L. The frequency of the first overtone N1 will then be

$$N1 = V/L$$

Second overtone :

To get the second overtone we will have to insert one more node and antinode.

an	n	an
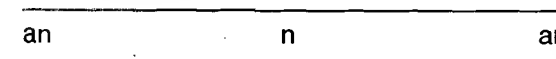
The wavelength of second overtone (length between the first antinode and the third antinode) is found to be two-third of the length of the tube, i.e., 2/3 of L or 2L/3. N2 its frequency will then be

$$N2 = V \div 2L/3 = 3V/2L$$

If we now compare the frequencies of the fundamental and the different overtones then we come to the following equation.

$N = 1/2 (V/L)$

$N1 = 1 (V/L)$

$N2 = 3/2 (V/L)$

In other words $N1 = 2N$, $N2 = 3N$ and so on and the ratio is

$N : N1 : N2 = 1 : 2 : 3.$

This is the same pattern as was obtained in the case of a vibrating string.

Vibration of air coloumn in a tube closed at one end :

In this case one end must always be a node, and the other an antinode. The air at the open end will move in and out alternately, the amplitude of the vibration being greatest at the opening end and diminishing as we approach the closed end.

The distance from node to antinode in this case is L, the whole length of the tube. To repeat, wave length is the distance between a node and the third node. The length of the tube L is the length between one node and the next antinode. So the wavelength will have to be four times this, i.e., 4L. The frequency N then is

$N = V/4L$

Overtones in Air coloumn in tube closed at one end :

[See also the enclosed figure]

Fundamental tone :

The fundamental has a frequency, as noted above,

$N = V/4L$

First overtone :

For the first overtone we have to insert a node and an antinode.
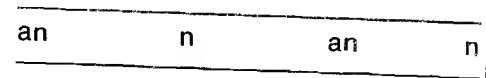
The length beween the first node (from the right) and the second node is two-third the length of the tube, i.e. 2/3 of L. The wavelength would be twice that, i.e., 2 X 2L/3 equal to 4L/3. The frequency N1 of the first overtone would be

$N1 = V \div 4L/3 = 3V/4L$

Second overtone :

For the second overtone we have to insert another set of node and antinode.
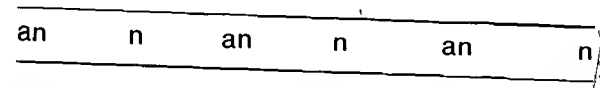
The length between the first node and the third node (which is the wavelength) is found to be four-fifth of the length of the tube, 4/5 of L or 4L/5. The frequency of the second overtone N2 would be

$N2 = V \div 4L/5 = 5V/4L$

If we now compare the frequencies of the fundamental and the different overtones then we come to the following equation.

$N = 1/4 (V/L)$

$N1 = 3/4 (V/L)$

$N2 = 5/4 (V/L)$

In other words $N1 = 3N$, $N2 = 5N$ and so on and the ratio is $N : N1 : N2 = 1 : 3 : 5.$

Comparison to the vibrations in the two tube :

Now when we compare the overtones generated in open tube and in a tube closed at one end we find that in the open tube all frequencies of the harmonic series, namely, 1, 2, 3, 4, 5 etc. are present. However in the tube closed at one end only the odd members of the harmonic series, namely, 1, 3, 5, 7 etc. are present.

Vibrations of air coloumn in a Conical tube closed at one end:

The behaviour of vibration of an air coloumn in a Conical tube is a complex one but to an extent we may say that behaves like as it were an open cylindrical pipe of same length - i.e., its wavelength is 2L, and it gives the full harmonic series.

Acoustical principles underlying Flute and Nagasvaram

Flute

Production of sound :

The instrument is held transverely with mouth-hole slightly turned outwards with the lower lip of the performer resting on the near edge of the hole. A blade-shaped column of air is then blown across the edge of the mouth-hole for the production of the sound. This column of air and the one inside the cylindrical pipe together comprise the vibrating system.

When all the holes are closed the flute gives the note of an open pipe whose length is the distance between the mouth-hole and the open end. Helmholtz was the first scientist to explain the production of sound and its maintenance in this instrument. His explanation consists in regarding the blade-shaped column of air coming from the mouth of the player as a sort of reed vibrating under the action of the air column in the tube. The vibration of the air

inside the tube causes the air reed altenately to enter or pass over the mouth-hole. That is during a condensation inside the pipe the blade-shaped column is sucked in and during a rarefaction the blade is thrown out. But Helmholtz has not been able to explain satisfactorily how the vibration starts in the air column of the tube.

This explanation has been supeseded by the modern researches of E.G.Richardson and others. They explain the working of the flute on the basis of the vortex motion and "edge-tones". The phenomenon of the edge-tones bear a resemblance to "Aeolian tones", a familiar example of which is the singing of the telegraph wires.

When a stick is held vertically in a flowing stream of water the formation of eddies on either side of the stick with its cores parallel to it can be observed. These vortices will be found to revolve in opposite directions which will soon be detached and carried along with the stream. a periodic push and pull will be experienced by the stick in a direction at right angles to the stream making it vibrate transversely. The same phenomenon happens when the obstacle is moving in a stationary fluid.

What is true for water flowing past an obstacle, or of an obstacle drawn through water, is equally true if we substitute air for water. The fluttering of a flag in the breeze is due to the flag-pole acting as an obstacle to the air-stream. Eddies are shed from opposite sides of the pole alternately, and chase one another along opposite sides of the flag.

When there is wind blowing we often notice the singing of telegraph wires - a singing which communicates itself from the wires to the posts and can be well heard when we press an ear to the post. The response of the wire to the action of the wind will, of course, be strongest when if the wire on which the wind acts is stretched so that its natural frequency of vibration is the same as the frequency imposed on it by the wind. That is if the frequency of the eddies when they are formed past a wire in an air stream coincides with one of the natural frequencies of the wire an "Aeolian tone" is produced.

The "edge tone" which resembles the "Aeolian tone" is produced when a blade-shaped column of air from a slit strikes a sharp edge of an obstacle. This is what happens at the mouth-hole of the flute.

It has been found that the "edge tone" rises in pitch with the pressure of the air that is blown. But in the flute the air column inside limits the pitch of the "edge-tone" to its natural series. For instance, if the blowing pressure is continually increased though the frequency of the "edge-tone" increases along with it, things settle only when the octave of the pipe is heard. Thus the note of the flute jumps an octave.

Production of Svara-s :

The manipulative mechanism for the production of the notes of the scale consists in regulating the effective length of the tube in use by covering the lateral holes wholly or partially with the fingers. It is noticed that the lateral holes are not arranged from the mouth-hole at distances corresponding to the frequencies of the notes produced in an open pipe. To a certain extent it can also be considered as an "Helmholtz resonator".

In this class of resonators the opening to the external air is very small in comparison with the enclosed activity. It is known that in this resonator the pitch can be raised by enlarging the opening. This fact is used by the flutist while playing. Uncovering the holes is equivalent to enlarging the opening of the resonator and the larger a hole is, the greater is its effect in raising the pitch.

It can also be understood now why when the first holes are made, if the instrument does not give a true scale, the holes are altered in size to correct the errors.

Material of Flute :

The quality of the note produced is affected to a certain extent by the material of which the flute is made and by the bore of the pipe. It has been shown by Helmholtz that the quality depends on the overtones in the note produced.

Theoretically small bore pipes will have a large retinue of upper partials while wide pipes will have fewer upper partials. Helmholtz has found that the flute notes contain very few and feeble overtones. Later work on the acoustic spectrum of the flute notes has also confirmed this. He attributes the soft and smooth quality of the flute notes as contrasted with those of violin and reed instruments to this fact. He also attributes the less penetrating tonal quality of the wooden flutes compared to the metal ones to the more yielding properties of the wooden sides.

Nagasvaram

Nagasvaram is a reed instrument. Wind instruments function with single reed or with double cane reeds. The clarinet is an example of a single cane reed instrument. Oboe and Nagasvaram are examples of a double cane reed instruments. Harmonium too is a reed instrument in which for every note in the musical scale a reed has been provided in the instrument.

Role of the reeds :

In the nagasvaram two reeds are bound together at their roots leaving an orifice at their free ends. After inserting this piece into the conical pope the player holds it in his mouth and blows air into it. The reeds then beat against each other and vibrate. They alternately open and close the aperture. The varying pressure is communicated to the column of air in the pipe. In these instruments conical pipes are used instead of cylindrical pipes. The air column also vibrates and the pitch of the resulting sound is determined by the air column. The coupling between the reed and the pipe must be tight, otherwise the reed will escape from its bondage and vibrate with its natural frequency. The "quack" or "peep-peep" sound heard sometimes when an unskilful player plays on the nagasvaram is due to the natural vibration of the reed.

The pipe in the nagasvaram will be two to two and half feet long. The longer the pipe the lower will be its 'sruti' or 'tonic'. The conical pipe is provided with side holes. The pipe

contains twelve side holes, eight in one line and the remaining four being distributed on both sides of this line near the bottom. Only seven holes are used for fingering. The others are intended to regulate the pitch of the instrument.

Tonal quality :

The tonal qualities of these reed instruments depend upon a number of factors. The air column, the material and shape of the pipe are the major factors controlling the quality. Since the clarinet pipe is cylindrical with one end closed, the overtones obtained are only the odd members of the harmonic series. In the case of oboe and nagasvaram, the tube being conical, all the harmonics (both even and odd) are obtained.

Role of the Bell-end :

The bell-shaped lower part of the nagasvaram is found to introduce even partials to reinforce the already exisiting ones. It also is found to reduce the intensity of the higher partial tones. The more important influence is that it helps to radiate the sound more efficiently in the atmosphere.
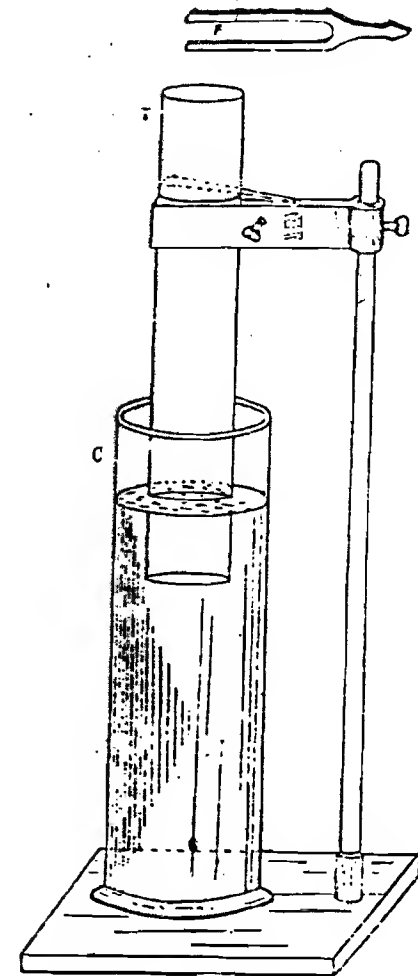
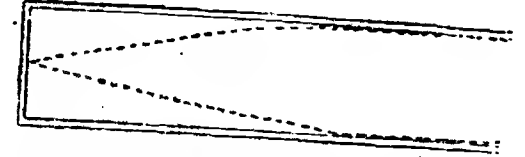Resonance of air column

(A)

(B)

(C)

(D)
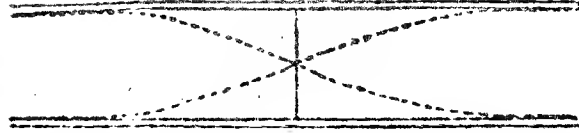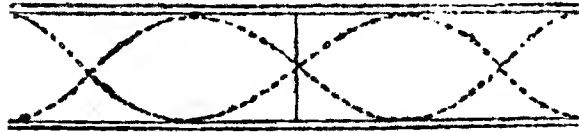
இரண்டு பக்கங்களும் திறந்த குழாயில் காற்றில் பல எண்டங்கள்
உற்படதும் விதத்தை விளக்கும் படம்

Overtones in open tube
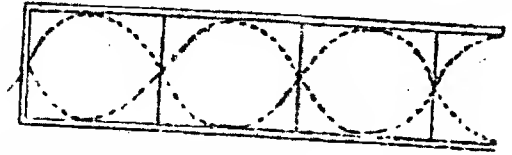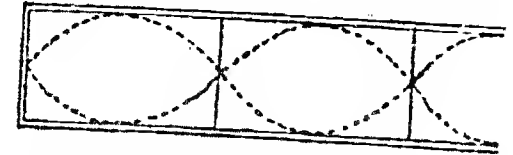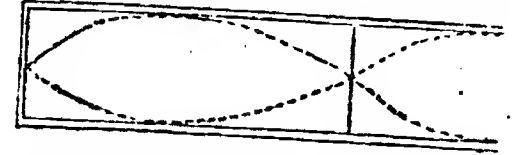
ஒரு பக்கம் திறந்த குழாயில் உள்ள காற்று பல எண்டங்களாக
துடிக்கும் விதத்தை விளக்கும் படம்

Overtones in a tube closed at one end.

LESSON NO. 5

Vibrations of Stretched Membranes

Vibrations of stretched membranes are used in skin covered instruments like Mrdangam and Tavil. The drums have two or three layers of skin. The outer layer is struck, and the others are set in vibration owing to the fact that the membranes are coupled by the enclosed air. A study of the membranes shows that energy surges from one to the others, the membrane which is struck losing its energy to the others and almost ceasing to vibrate, and then gaining energy from the others, while they in turn ceasing to vibrate. this exchange gose on until the energy of the blow is exhausted.

The possible modes of vibration are easily derived theoretically and demonstrated practically. In the fundamental the membrane vibrates as a whole, with an antinode (maximum displacement) at the centre and a nodal line (no displacement) round the round the rim. The frequency is

1) inversely proportional to the diameter of the membrane

2) 2directly proportional to the square root of the tension.

3) inversely proportional to the square root of the mass of the membrane per unit area.

In these instruments the membrane is usually stretched either on a shallow frame (kanjira) or a cavity. the membrane is set in vibration either by direct percussion of the hand (mrdandgam) or with a stick (tavil). A circular membrane alone is used in preference to other shapes. The mathematical treatment of such a circular membranes has been fully discussed by Lord Rayleigh.

*The membrane as it vibrates alternately compresses and expands the air in the cavity. This reacts on the membrane and changes its natural frequencies. Further the drums are

not only struck at the centre but also at other points between the centre and the edge. The modes of vibration in drum can be studied in a general way by the well-known Chladni's device of strewing fine sand on the membrane.

Chladni used a glass or metal plate as his source of sound. In one form the plate is square and is fixed at the centre. It is stewn with sand and set in vibration by applying a violin bow to one point of edge and touching another point. The sand tends to collect in the still places known as the nodal lines. These are the lines where there is no displacement or where the membrane is at rest.

[See the enlcosed figure]

Acoustical Principles underlying Mrdangam and Tavil

The above mentioned details regarding vibration of membranes apply to mrdangamä and tavil. Certain specific features are mentioned below.

Loading the skin :

Both in Mrdangam as well as in Tavil we find the skin is loaded with some material.

In the mrdangam at the centre of the right skinhead is applied a paste consisting of boiled rice, manganes dust and tamarind juice. This is spread uniformly and the quantity is increased till the sounds obtained by striking the head at its middle and the edge agee in pitch. These sounds are known as "capu" and "mittu" in musical parlance. Thus on the right head a clear perdptible pitch can be elicited and thus mrdangam becomes a rare membranophone which can be 'tuned'.

On the left side just before the instrument is to be played a mixture of 'ravai' and water is applied to the centre and this plaster is rmoved carefully after each performance.

In tavil too on the left side (the side which is struck with a stick), on the inner skin (facing the hollow of the wooden shell) a mixture of castor oil, ashtabandhanam, nandi-

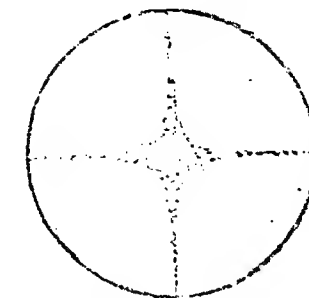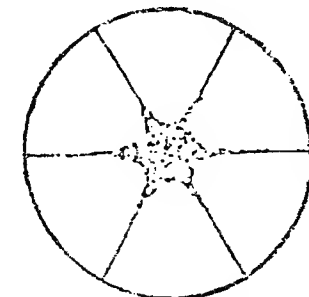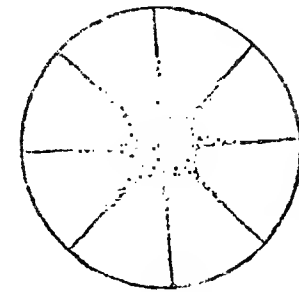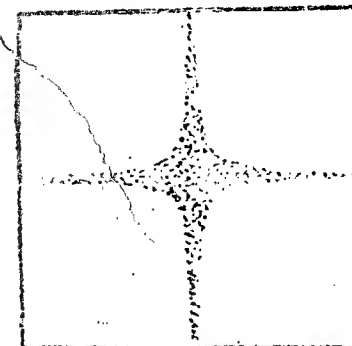mozhukku (coating from an anointed stone idol) mixed to a specific consistency - is applied.
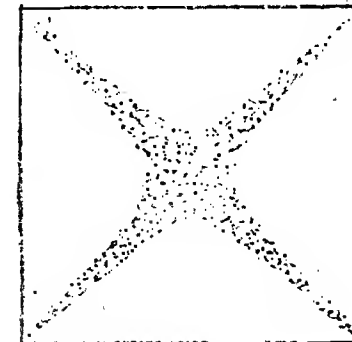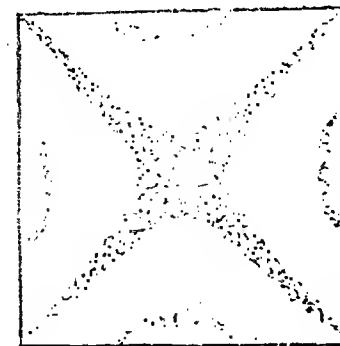
Circular membranes which vibrate normally produce overtones which are inharmonic (not conforming to the harmonic series). By loading the central zone the vibrating membrane gives rise to overtones which are harmonic. It has been theoretically established that if the weight or thickness of the skin is increased progressively from rim to the centre the overtones would become harmonic.

Quality and volume of tone :

The cylindrical chamber, in the case of both mrdangama and tavil, helps in production of the loud and pleasing sound.

Books referred :

1   "The Physics of Music" by Alexander Wood University of Paperbacks published by Methuen & Co. Ltd. London, 1969

2   "The Physics of Music" by R K Viswanathan, published by The Annamalai University, Annamalai Nagar., 1948

3   "Principles of Physics" by Earnest Greene, Prentice-Hall of India Private Limited, New Delhi, 1969.

CHALDNI'S FIGURES 49A

தகடுகளின் துடிப்பை கிளாக்திம் கிலவடல் கோலாங்கள்